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project record

San Dimas Equipment Development Center

Substitute Anchor Systems

bibliographies and abstracts of reports and list of patents

Forest Service U. S. Department of Agriculture

7824 1201

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SUBSTITUTE ANCHOR SYSTEMS

—Bibliographies and Abstracts of Reports
and List of Patents—

Compiled by—

FOREST SERVICE—U. S. DEPARTMENT OF AGRICULTURE
EQUIPMENT DEVELOPMENT CENTER
SAN DIMAS, CALIFORNIA

for—

ED&T Project No. 2640

Substitute Anchors for Aerial Cable Transport Systems

7824 1201

PREFACE

The San Dimas Equipment Development Center (SDEDC) is working on ED&T project No. 2640 to develop and field test substitute anchor systems for use with cable logging systems. Large stumps have traditionally served as cable anchors; however, older large stumps are deteriorating and new stumps are too small. Further, cable systems can be laid out more flexibly and moved more often when no longer dependent on stumps for anchors. Substitute anchors can be effective in combination with stump anchors to fill gaps where stumps are missing, deteriorated, or too small. SDEDC seeks to develop (1) substitute anchors for cable system guylines in typical forest soils, which may include mobile auxiliary equipment for rapid installation, testing, and recovery of anchors; and (2) early warning devices for anchor systems in low-strength installations.

One of the initial project tasks was a literature search conducted to determine the extent and availability of reports that address the topic of anchor systems. This search resulted in a compilation of the material presented in this Project Record. The reports and patents listed in sections A, B, and D are on file at the SDEDC technical library.

CONTENTS

A

bibliography list — with abstracts

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2.	Adams, J. K., and D. C. Hayes. 1967. Uplift capacity of shallow foundations. Ontario Hydro Research Quarterly, Vol. 19, No. 1, pp. 1-13, 1967.	C-1
3.	Adams, J. I., and T. W. Klym. 1972. A study of anchorages for transmission tower foundations. Canadian Geotechnical Journal, Vol. 9, No. 1, pp. 89-104, Feb. 1972.	C-1
4.	Aerojet-General. 1968. Propellant-actuated embedment anchor. Final report, Nov. 1968. Aerojet-General Corp., Research & Development Dept., Downey, Calif.	C-2
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abstracts of available reports

ABSTRACTS

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1963. Uplift tests on model anchors in sand and clay. The Hydro-Electric Power Commission of Ontario, Canada. Unpublished report, Sept. 1963.

ABSTRACT

Uplift tests were carried out in sand and clay with model anchors of different sizes embedded at various depths. Both short-term and long-term loading rates were used. Relationships were obtained between pullout capacities and the size and depth ratios of the anchors. Large differences between short-term and long-term capacities were observed for anchors buried in clay. A means of estimating long-term capacity, using drained shear-strength parameters, is suggested. It is recommended that the study be extended to full-scale field tests.

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1967. Uplift capacity of shallow foundations. Ontario Hydro Research Quarterly, Vol. 19, No. 1, pp. 1-13, 1967.

ABSTRACT

The resistance of soils to uplift loads was studied as an aid to the design of transmission-tower foundations. A review of previous theories and of experience within Ontario Hydro had shown a lack of any generally accepted theory. Simple model tests were carried out both in sand and in clay, for various anchor depth-to-width ratios. In sand the failure mechanism was found to be significantly influenced by the surface boundary and the relative density of the soil. In clays, negative pore-water pressures were observed which accounted for a large reduction in uplift resistance under sustained loading. Simple design relations both for sand and for clay were produced from the model tests; values calculated from these relations showed reasonable agreement with the results of a number of full-scale tests on augered concrete footings. The relations have been useful in estimating the uplift capacity of such footings. More rigorous solutions are needed, however, to enable estimation of footing movement both under vertical and under lateral loads.

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3. Adams, J. I., and T. W. Klym.
1972. A study of anchorages for transmission tower foundations. Canadian Geotechnical Journal, Vol. 9, No. 1, pp. 89-104, Feb. 1972.

ABSTRACT

A number of uplift tests have been conducted on anchors proposed for use to support high voltage transmission line towers both for the conventional four legged structure and for the guyed-type structure with a single central footing. Tests were carried out at seven sites, six in the Toronto-Barrie Area and one at Thunder Bay, Ontario. The soil conditions included very dense till, soft clay up to 130 ft (39.62 m) in depth, dense sand and gravel and loose to compact silty sand. The test installations included both power installed multi-helix anchors and grouted anchors with a single reinforcing rod. These were installed at various depths. In the very deep clay only multi-helix anchors were tested. Most of the tests were in uplift on anchors installed vertically. A few group tests were conducted both in uplift and compression. The results of all of the tests are presented along with fairly detailed information on the properties of the soil at each site. An attempt to anlyze the results of the helix anchor tests using simplified bearing theory was made. The grouted anchor tests were analyzed using either frictional or adhesive bond theory depending on the soil type. The results indicate that the theories using conventional soil properties provide reasonable design parameters for initial planning. Further confirmation by fullscale testing, however, is essential.

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1968. Propellant-actuated embedment anchor. Final report, Nov. 1968. Aerojet-General Corp., Research & Development Dept., Downey, Calif.

ABSTRACT

This report contains a review of the results of an engineering, development, and manufacturing program for the development of a propellant-actuated embedment anchor. The objective of the program was to provide a prototype anchor system suitable for marine salvage operations. Calculations and engineering discussions are presented to support the design concept and certain specific components contained in the system. Test results are reviewed to define the demonstrated performance capability of the anchor in a variety of sea-floor compositions. Numerous photographs and drawings are included to illustrate the various anchor system components and to document the development test operations. Several appendixes are included to define specific test procedures, some of which are applicable to a general, future proof-test and evaluation program.

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1966. Pullout load capacity of a circular earth anchor buried in sand. Highway Research Record 108, pp. 1-10.

ABSTRACT

The results of pullout load capacity tests performed on numerous small-scale model earth anchors are presented. The techniques of dimensional analysis are used to develop empirical relationships among anchor size, depth of anchor embedment, and pullout capacity for single anchors of of circular cross-section buried in a dense uniform sand. A distinction is made between shallow and deep anchors. The range of the ratio of depth of embedment to anchor diameter studied corresponds to the general range found in field applications of earth anchors that are used to provide tieback resistance for retaining structures and uplift resistance for transmission towers, utility poles, moorings, etc. The results of two full-scale field tests of Webb-Lipow type anchors are also reported.

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6. Balla, A.
1961. The resistance to breaking-out of mushroom foundations for pylons. Proceedings of Fifth International Conference of Soil Mechanics Foundation Engineering, Paris, July 17-22, 1961, Vol. 1, pp. 569-576.

ABSTRACT

Mushroom foundations are highly resistant to breaking out. This property is of particular importance where the foundations are for pylons supporting electrical power lines. The author reviews the research which he undertook on breaking out resistance of such foundations.

Laboratory model tests proved that the form of the breaking out earth body resembles a solid of revolution. The meridian section of this may be a circle, the tangent of which is vertical at the upper edge of the foundation slab; at ground level, however, the tangent intersects that latter at an angle of $\frac{\pi}{4} - \frac{\varphi}{2}$.

The entire breaking out resistance can be obtained by calculating the dead weight of the breaking out earth and foundation bodies and the value of the resultant shear stress acting on the sliding surface. The breaking out resistance is proportional to the third power of the foundation depth; it depends on the physical characteristics of the soil and on the relationship between the foundation depth and the diameter of the foundation slab.

Results obtained from theoretical considerations supplemented by scale model tests and full scale field tests, respectively reveal the breaking out force and the variations which arise from different factors.

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7. Bayles, J. J., and R. E. Jochums.
1965. Underwater mooring system. U. S. Naval Civil Engineering Laboratory, Technical Note N-662, Port Hueneme, Calif., Apr. 1965. NTIS/AD 461 146.

ABSTRACT

On 17 July 1961, a sea water environment test was initiated to determine the useful life of a 7/64-inch-diameter galvanized steel cable, sheathed with a 0.020 polyethylene coating. This specific work was undertaken as a part of NCEL Task NUSL-16407, Development of a Container for a Master Repeater Unit (see NCEL Technical Report R-324).

The test cable had a proven breaking strength of 1600 pounds. The test consisted of an underwater mooring of a 32-foot-long, 20-inch-diameter cylinder with 700 pounds of positive buoyancy. This cylinder container was lowered to a depth of 130 feet at its lower end, held by the test cable attached to a 1500-pound concrete clump anchor.

The design life of the test cable was six months. The container was found adrift approximately one mile from its moored position on 23 September 1964, three years and two months after installation.

There are reasons to believe that the test cable's useful life far exceeded its design life due to the protection against sea water corrosion of steel cable provided by polyethylene coating.

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8. Beard, R. M.
1973. Direct embedment vibratory anchor. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report TR-791, June 1973. NTIS/AD-766 103.

ABSTRACT

A direct embedment anchor driven by vibration was developed and tested by the Naval Civil Engineering Laboratory for use in deep ocean mooring systems. This report describes the second generation anchor and the modifications required to evolve it from the prototype anchor. Procedures for selecting anchor fluke size for different sediment conditions through estimations of anchor penetration and short-term holding capacity are given. It is concluded that the modifications made to the prototype vibratory anchor have increased its versatility, improved its reliability, and eased its handling aboard a ship at sea. Based on test results, it was found that the vibratory anchor can provide between 25,000 and 40,000 pounds of short-term holding capacity in a range of seafloor condition. Operational experience indicates that the anchor will be limited to deployment from anchored or dynamically positioned work platforms.

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9. Bemben, S. M., E. H. Kalajian, and M. Kupferman.
1971. The vertical holding capacity of marine anchors in sand and clay subjected to static and cyclic loading. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Contract Report CR 72.007, for University of Massachusetts, Amherst, Mass. NTIS/AD 735950.

ABSTRACT

The purpose of this investigation was to experimentally measure and then to evaluate the influence, if any, of different loading conditions on the vertical holding capacity of marine anchors embedded in sand and in clay. The NCEL design fluke was used in both soils and, in addition, other fluke designs were used in the sand tests.

Small and medium scale indoor laboratory tests and outdoor field tests in a specially constructed tank facility were conducted. In addition, small scale semi-spacial laboratory tests on half-sectioned anchors against a plexiglass viewing face were conducted. Controlled static and cyclic loading patterns were applied by specially designed loading devices and vertical movements were noted by ordinary visual and automatic recording devices.

The experimental data was utilized to develop design curves for similar anchor assemblies and the results are compared to previously published empirical formulas for the prediction of the holding capacity. The results confirm the anticipated assurance of different shallow and deep mechanisms of failure in both soils.

The predictions for the holding capacity for anchors in clay and in sand in the shallow mechanism of failure and also for anchors in clay in the deep mechanism, when subjected to static loadings, are found to be in good agreement with cited previous formulas. However, the prediction for the holding capacity for anchors in sand, subjected to static loadings, in the deep mechanism are not in good agreement with any previous formulas.

The effect of a cyclic loading pattern as compared to a static loading pattern was observed and the detrimental effect of a continuous cyclic creep behavior on the useful life of an anchor is noted.

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10. Brackett, R. L., and A. M. Parisi.
1975. Hand-held hydraulic rock drill and seafloor fasteners for use by divers. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R 824. NTIS/AD-A014202.

ABSTRACT

Underwater construction operations require an improved diver-operable rock drill and efficient and realiable seafloor rock fasteners. An experimental hydraulically powered rock drill was fabricated from commercially available components. The results from the shallow-water testing of this drill were used to design a prototype underwater rock drill capable of operating to ocean depths of 120 feet. Testing of the prototype rock drill revealed that it either met or exceeded initial performance requirements.

Four brands of expansion-type rock bolts were investigated for use as seafloor rock fasteners. Also, a new type of rock bolt was developed for use in coral seafloors. Results of short- and long-term tests are presented along with a summary of important design parameters.

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11. Bradley, W. D.
1963. Field tests to determine the holding capacity of explosive imbedment anchors. U. S. Naval Ordnance Laboratory, White Oak, Md., NOLTR 63-117, July 10, 1963; published Nov. 1963. NTIS/AD 422984.

ABSTRACT

The first objective of these tests is to determine the feasibility of using the explosive imbedment anchor as an anchoring device for a submerged, buoyant chamber. The second objective is to determine the effects of sediment strength and anchor characteristics on the penetration and holding capacity of imbedment anchors. Twenty explosive imbedment anchors were purchased from the PneumoDynamics Corporation. Ten of these anchors were Mk V SEASTAPLES, rated at 3500 pounds holding capacity; and ten were Mk II SEASTAPLES, rated at 250 pounds. Measurements were made of the anchors' holding capacity off Santa Barbara, California; Fort Lauderdale, Florida; and Solomons Island, Maryland. Bottom sediment samples were taken at each test location. These samples were analyzed so that bearing strengths of the sediments could be calculated. The pull-out loads applied to the Mk V SEASTAPLES ranged from 1920 pounds at Fort Lauderdale to 460 pounds at Solomons Island. The pull-out loads applied to the Mk II SEASTAPLE ranged from 210 pounds at Solomons Island to 1220 pounds at Fort Lauderdale. A comparison of the calculated holding capacities with the measured pull-out loads shows that the anchors failed to key properly on many of the tests. It is concluded that, although the imbedment anchor is usable as an auxiliary (or back-up) anchor, additional tests are required, with anchors that operate properly, in order to completely meet the objectives of this test series.

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12. Broms, Bengt B.
1965. Design of laterally loaded piles. Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, pp. 79-99, May 1965.

ABSTRACT

The ultimate lateral resistance and the working load deflections of single piles and of pile groups depend on the dimensions, the strength, and flexibility of the individual piles, and on the deformation characteristics of the soil surrounding the loaded piles. Methods are presented for the determination of the ultimate lateral resistance based on the concept that the ultimate lateral resistance at relatively small penetration depths is governed by the passive lateral resistance of the soil surrounding the loaded piles, and that the ultimate lateral resistance at relatively large penetration depths is governed by the ultimate or yield resistance of the pile section.

The concept of over-load and under-strength factors is introduced. The numerical values of these factors depend on the danger of loss of human lives and the economic consequences in the case of failure. Accordingly, the factors have been so chosen that the probability of failure is less than a certain quantity.

Methods for the calculation of lateral deflections at working loads are presented. These methods are based on the concept of a coefficient of subgrade reaction. It has been assumed that the coefficient of subgrade reaction increases linearly with depth in the case of cohesionless soils and that it is constant with depth for cohesive soils.

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13. Broms, Bengt B.
    1964. Lateral resistance of piles in cohesive soils. Journal of the Soil Mechanics and Foundation Division, Proceedings of the American Society of Civil Engineers, pp. 27-63, March 1964.

ABSTRACT

Methods are presented for the calculation of the ultimate lateral resistance and lateral deflections at working loads of single piles and pile groups driven into saturated cohesive soils. Both free and fixed headed piles have been considered. The ultimate lateral resistance has been calculated assuming that failure takes place either when one or two plastic hinges form along each individual pile or when the lateral resistance of the supporting soil is exceeded along the total length of the laterally loaded pile. Lateral deflections at working loads have been calculated using the concept of subgrade reaction taking into account edge effects both at the ground surface and at the bottom of each individual pile.

The results from the proposed design methods have been compared with available test data. Satisfactory agreement has been found between measured and calculated ultimate lateral resistance and between calculated and measured deflections at working loads. For design purposes, the proposed analyses should be used with caution due to the limited amounts of test data.

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14. Brown, G. A., and V. A. Nacci.
    1971. Performance of hydrostatic anchors in granular soils. Offshore Technology Conference, Dallas, Texas, Apr 19-21, 1971, paper no. OTC 1472.

ABSTRACT

Preliminary laboratory tests have been performed to study the behavior and the flow characteristics of a hydrostatic anchor in a granular soil. Both large-scale (10-inch OD) model tests and electric analog tests were performed. Data from these tests are presented and analyzed. The hydrostatic anchor appears to offer high reaction to weight ratio, reusability, and reversibility when compared with conventional anchor systems.

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15. Colp, John L., and John B. Herbich.
1972. Effects of inclined and eccentric load application on the breakout resistance of objects embedded in the sea floor. Texas A&M University, Sea Grant Publication No. TAMU-SG-72-204, May 1972.

ABSTRACT

The expansion of the field of coastal and ocean engineering has resulted in a great increase in applications for floating equipment anchored in shallow and deep water. Many of these applications impose a stringent station-keeping requirement. One of the solutions for such applications is the use of taut-line embedded mooring systems. Previous theoretical and experimental studies of such systems have been restricted to shallow-buried anchors with vertical load application. This study considers the forces required to break out model circular plate anchors embedded into three soil materials at depths of two and eight diameters when the load application is inclined from 90 degrees to 45 degrees from the horizontal and is attached from the mid-point over to one edge of the plate.

A review of past published contributions on the subject of mooring and anchoring systems, embedded anchors, and anchor withdrawal studies is included. Previous attempts at the explanation of the mechanisms invoked during anchor pullout using existing soil mechanics theory are discussed and the resulting quasi-theoretical equations are given.

A laboratory investigation of the displacement of individual particles of a simulated, dense, granular, cohesionless soil under inclined and eccentric load applications was conducted using a proven experimental technique involving a plane array of cylindrical, steel rollers. The displacements of the particles were observed through a plexiglas tank face and were recorded photographically.

Model pullout tests using a three-inch diameter plate buried in tanks of three different soils -- dense, dry, Ottawa sand; dense, submerged Ottawa sand; and Gulf of Mexico marine sediments -- were performed. Maximum pullout forces required to breakout the model anchor under various inclined and eccentric load applications were recorded. The effects of two depths of burial -- two plate diameters and eight plate diameters -- were investigated.

Observations from the dense, dry sand tests indicated that the maximum required pullout force increased as the inclination angle moved from 90 degrees to 45 degrees from the horizontal. For the marine sediments investigated, the maximum pullout force also increased as the inclination angle changed but at a much smaller rate. The submerged sand deeply-buried pullout tests exhibited an anomaly in that the pullout force decreased at the 45 degree inclination. It is postulated that this result involves the action of pore water pressures activated during withdrawal.

The dense, dry sand tests indicated that, as the point of load application moved from the center to one edge, the maximum pullout force required

decreased. The marine sediments exhibited a similar decrease but at a very slow rate for the deeply-buried case. The submerged sand deeply-buried tests displayed the same anomalous behavior as in the inclination study.

The data obtained from the dry sand and marine sediment model tests were examined using a dimensional analysis technique. A display of a dimensionless pullout force term containing inclination, eccentricity, plate diameter, and soil shear strength factors versus a dimensionless depth of burial term is given. Two distinct regions of the data, one for granular materials and the other for cohesive materials, were observed. A Wilson-Goodlet multiple regression analysis was performed and provided equations of a straight line for each material utilized in the experimental work which can be used for design purposes.

A bibliography containing fifty-three entries is included.

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16. Dantz, Paul A.
1968. The padlock anchor - a fixed-point anchor system. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R-577, May 1968. NTIS/AD 669113.

ABSTRACT

The objective of this study was to investigate the feasibility of combining propellant-activated embedment anchors and a structural frame with bearings pads to provide a fixed-point, deep ocean anchorage system. The work was to include the conception, design, fabrication, and evaluation. This report describes the resulting device, termed PADLOCK, discusses its development, and documents the field tests and results.

Essentially the PADLOCK is a tripodal frame terminating in 6-foot-diameter bearing pads that are locked to the sea floor through activation of 20,000-pound (nominal holding power) embedment anchors, one per bearing pad. Shallow water tests demonstrated that the components are operationally compatible as a system and that the embedment anchors can be detonated singly or as a group. A limited number of tests showed the reliability of the complete system to be low, mainly because of the performance of the embedment anchors.

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17. Dantz, Paul A.
1966. Light-duty, expandable land anchor (30,000-pound class). Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R-472, August 1966. NTIS/AD 640232.

ABSTRACT

This study developed a family of two-fluke, light-duty, expandable land anchors that have ultimate vertical holding strengths of 30,000 to 60,000

pounds in sand and clay soils. It also includes a method of installation for these anchors that reduces excavation to the boring of either a 3- or 6-inch-diameter hole.

The anchors when closed form a nominal 3- or 6-inch circular cylinder. After installation, two flukes are opened by the soil action to hold the anchor in the soil.

One hundred and fifty-six field tests were conducted to evaluate the anchor design, vertical and horizontal holding strength, structural strength, opening characteristics, fluke length, overburden depth, and installation equipment and techniques. Recommendations on the use of these expandable anchors are included.

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18. DeHart, R. C., and C. R. Ursell.
1967. Force required to extract objects from deep ocean bottom. Southwest Research Institute, San Antonio, Texas, prepared on contract for The Structural Mechanics Branch, Office of Naval Research, Sept. 19, 1967. NTIS/AD 658757.

ABSTRACT

A preliminary investigation of the force required to extract an object from the bottom of the ocean was conducted. Ocean depths equivalent to pressures of 3000 psi were simulated and the effect of soil type, object size and object configuration was studied.

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19. Drucker, M. A.
1934. Embedment of poles, sheeting, and anchor piles. Civil Engineering, Vol. 4, No. 12, December 1934, pp. 622-626.

ABSTRACT

Engineers whose work involves the erection of poles for supporting electrical conductors or the design of sheet-pile retaining walls, with their anchor piles, will find in this article a new approach to an old design problem. Little has appeared concerning stability problems of this kind in American engineering literature. In this article, Mr. Drucker presents diagrams for the quick determination of the safe depth a pole should be embedded in the ground to sustain a given horizontal load and derives the formulas on which the curves are based. Briefly, he treats of the theory involved in increasing the resistance of a pole to pull-over or breaking by adding concrete collars and special anchorages to that part of the pole in the ground. Also he considers the depth to which sheeting should be driven, and the safe load for an anchor pile behind a sheet-pile retaining wall.

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20. Fox, D. A., G. F. Parker, and V. J. R. Sutton.
1970. Pile driving into North Sea boulder clays. Second Annual Offshore Technology Conference, Houston, Texas, April 22-24, 1970, Paper No. OTC 1200.

ABSTRACT

The British Petroleum Company West Sole Gas Field was the first offshore discovery in the United Kingdom sector of the North Sea to be exploited commercially.

In 1966 two multiwell fixed-leg drilling platforms and two smaller platforms were installed in about 90 ft mean water depth, founded on steel pipe piles driven into hard Boulder clays and shaly Lias Clays. Design penetrations based upon static soil mechanics underestimated the pile bearing capacities developed in these clays, while the capability of the hammers to drive piles to the required bearing capacities was overestimated.

A third multiwell drilling platform was fabricated in 1967 with the design modified to overcome the difficulties encountered in the original pile driving, but it was not installed until 1969 by which time limited experience had been gained in the operation of the Wave Equation analysis based upon various publications. It was found that some of these analyses could lead to widely varying estimates of ultimate resistance.

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21. Frohlich, H., and J. F. McNary.
1969. A hydrodynamically actuated deep sea hard rock corer. Marine Technology Society Journal, Vol. 3, No. 3, May 1969, pp. 53-60.

ABSTRACT

The progress of several important geological studies is strongly handicapped by the lack of an efficient deep sea hard rock coring tool. A new, hydrodynamically actuated rock sampler has yielded promising results. Comparable in weight and in speed and ease of handling to regular gravity corers, the new instrument is capable of producing impact forces of several million newtons.

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22. Gordon, D. T., and R. S. Chapler.
1972. Vibratory emplacement of small piles. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1251, Dec. 1972. NTIS/AD 906997.

ABSTRACT

An experimental study was conducted to evaluate vibratory emplacement techniques for small piles. A vibratory pile driving system utilizing a

hydraulic piston actuator was designed, assembled, and tested. The general effects of driving frequency, surcharge, driver power, and tip driving were evaluated. Tests were conducted to compare the vibratory driving with impact driving.

Although rapid penetration rates were achieved with the vibratory system, this advantage was minimized due to the short total driving time. Therefore, it was concluded that a small vibratory pile driver must compete with impact hammers in size, portability, and efficiency. A large system surcharge appeared to be an inefficient method of achieving penetration in difficult terrain. Instead, it was recommended that a linkage be designed to provide rapid impact capability for the actuator in difficult conditions.

A small, self powered, hydraulic system of this type could perform several construction site tasks. The vibratory capability could be used to rapidly emplace or extract piles, stakes, and ground anchors. The rapid impact mode could be used to penetrate difficult soils and to carry out various demolition tasks.

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23. Harvey, R. C., and E. Burley.
1973. Behaviour of shallow inclined anchorages in cohesionless sand. Ground Engineering, Vol. 6, No. 5, Sept. 1973, pp. 48-55.

ABSTRACT

The aim of the present investigation is to examine the behaviour of small-scale shallow inclined anchorages buried in sand having a negligible cohesive strength. A theoretical approach was formulated connecting the variables involved and predicting the ultimate pull-out force of the anchorages.

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24. Hironaka, M. C.
1974. Anchoring in snow, ice, and permafrost. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1344, June 1974. NTIS/AD 782580.

ABSTRACT

A literature search was conducted to identify techniques, procedures, and equipment that are used for anchoring in snow, ice, frozen ground, and permafrost in arctic regions. The results of that search together with findings and recommendations for future research and development is reported herein.

Anchors in snow, ice, frozen ground, and permafrost will creep in proportion to the magnitude of the load. Thus, the design of anchors to be placed in these media will be governed more by the displacements that can be tolerated than by uplift capacities.

Although many basic anchor configurations have been used for ground anchors, the applicability of such anchors for use in the media discussed above are somewhat limited. The more common anchor types that have been used in these materials include the following: round plate anchors (snow); pile anchors (ice); and dead man, piles, grouted rod anchors, hook anchors, arrowhead universal ground anchors, and various other small stake-like anchors (frozen ground and permafrost). Of all the anchors mentioned for frozen ground, the grouted rod anchor is believed to be the best. Analytical techniques to describe the behavior of anchors in these media have generally not been verified.

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24A. Howat, M. D. SEE PAGE C-15A.

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25. Hueckel, S.
1957. Model tests on anchoring capacity of vertical and inclined plates. Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering, London, Aug. 12-24, 1957, Vol. 2, pp. 203-206.

ABSTRACT

The paper deals with model tests carried out for the determination of anchoring capacity of vertical and inclined plates embedded in beach sand. The form of sliding wedge, the influence of inclination of plates and of distance between the plates is discussed.

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26. Kalajian, E.
1971. The vertical holding capacity of marine anchors in sand subjected to static and cyclic loading. PhD thesis, University of Massachusetts, Amherst, Mass., June 1971.

ABSTRACT

The design of several types of anchorage and mooring systems for ocean installations involves an assessment of the vertical holding capacity of embedded anchorage assemblies. These assemblies are often subjected to cyclically applied loads due to wave action.

In this study, each anchor assembly consists of a rigid pipe stem and a rotating fluke. The assembly is inserted in saturated sand to depths of 10 feet by a vibrator unit mounted at the top of the pipe. As the load to be held is applied, the fluke rotates from its desirable orientation during insertion to its desirable orientation during holding. The flukes are patterned after the U.S. Naval Civil Engineering Laboratory fluke shape. The results of static and cyclic load tests with fluke sizes up to 220 and 65 square inch horizontal projected areas, respectively, are presented.

A specially constructed outdoor test tank facility was utilized for the major portion of the study. The tank is 20 feet by 20 feet in plan by 11 feet deep. The test tank appurtanences include a backflushing water

pressure system for the periodic loosening of the sand after a series of tests have been completed, a movable reaction frame with static and cyclic load applying devices, and load and vertical movement measuring instrumentation. The static loads are applied by a hand operated winch while the cyclic loads are applied by a specially constructed device. The cyclic loads are applied with a sine wave form with controlled frequency and amplitude of load. The applied loads are sensed by strain gage and automatic recorder instruments. The vertical movements are observed by vertical survey control and/or by an electric displacement transducer. In some tests, both the total holding capacity and the fluke alone holding capacity are simultaneously measured.

Results of the static loading tests indicate that there are separate mechanisms of failure for shallow and deep embedments of an anchor fluke in saturated sand. For the anchors tested, the relationships between the size, shape and depth of burial of the fluke, the type of loading and the engineering properties of the soil are discussed.

Cyclic loads as characterized by the sinusoidal loading pattern used in this investigation have a pronounced degrading effect on the holding capacity of an anchor assembly embedded in loose saturated sand. Relationships between the rate of movement of the anchor assembly and the ratio of cyclic to static failure load are presented.

A theoretical approach to the prediction of the holding capacity of a deeply embedded anchor fluke is discussed. Design graphs which are useful for practical guidance in the design of embedded anchor assemblies subjected to static and cyclic loading are presented.

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27. Kalajian, E. H., and S. M. Bemben.
1969. The vertical pullout capacity of marine anchors in sand. University of Massachusetts, School of Engineering, Amherst, Mass., Report No. THEMIS-UM-69-5, Apr. 1969. NTIS/AD 689522.

ABSTRACT

This investigation considers the vertical pullout capacity of marine anchors embedded in sand by vibration. Small size anchors having projected horizontal areas of about 15, 30, 55, and 110 square inches were inserted to various depths ranging between 2 feet and 6 feet in a flooded sand soil and load tested for vertical holding capacities. The anchors were tested in a large scale outdoor test bin. For insertion, the anchors were attached to the lower end of a rigid pipe and vibrated into place by means of a vibrator unit attached to the upper end.

Test data indicates that for small size anchors having a short length of loading time, there appear to be two mechanisms of failure within the soil mass in which the anchor is embedded. The mechanism which develops is a function of depth of embedment, size and shape of the anchor, and sand density; and it controls the shape of the curve of pullout load versus anchor depth. The length of the loading time affects the pullout capacity

even though the permeability of the flooded sand is 0.1 feet per minute.

The data presented is applicable for the design of anchorages for ocean installations.

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28. Karafiath, L., and M. G. Bekker.
1957. An investigation of gun anchoring spades under the action of impact loads. Army Tank-Automotive Command, Report No. 19, Warren, Mich., October 1957. NTIS/AD 156419.

<u>ABSTRACT</u>

An investigation of conventional and novel gun spade types indicates that the "spaced link" spade as proposed in this report offers a prospect for the radical improvement of the anchoring power of the spade. Since new guns are expected to be more powerful, yet lighter because of air-portability requirements, a general method for gun spade evaluation has been proposed. This method is quite accurate in frictional soils and lends itself to limited use in cohesive soils.

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29. Kovacs, Austin.
1975. Hook anchor tests in frozen and unfrozen ground. Corps of Engineers, U. S. Army, CRREL, Hanover, N. H., Special Report 229, May 1975.

<u>ABSTRACT</u>

The findings of an exploratory study of the holding capacity of hook anchors in frozen and unfrozen ground are presented. Testing revealed that hook anchors are capable of being driven and retrieved from frozen silt and that their holding capacity was reasonably high in comparison to their size. Hook anchor capacity in the frozen silt at $-2^{o}C$ was found to be three times higher than in the unfrozen silt.

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30. Kovacs, Austin, and Scott Blouin, Bruce McKelvy, and Herman Colligan.
1975. On the theory of ground anchors. Corps of Engineers, U. S. Army, CRREL, Hanover, N. H., Jan. 1975. NTIS/AD/A-006 582.

<u>ABSTRACT</u>

The findings of a literature review of anchor design are presented to give a synopsis of the numerous theoretical and empirical techniques available for predicting anchor capacity. The review revealed that anchor capacity is related to anchor configuration, soil characteristics and depth of anchor embedment and that the mode of soil failure as a result of anchor loading is dependent upon soil type and state as well as on the ratio of the depth of anchor embedment to anchor diameter. As a result it was found that no single equation can be used to predict anchor capacity under all soil conditions or anchor embedment depths.

24A. Howat, M. D.
1969. The behavior of earth anchorages in sand. MS thesis, University of Bristol, 1969.

ABSTRACT

This thesis describes a model investigation of the behaviour of earth anchors buried in a homogeneous sand having some cohesive strength. The anchors investigated were spherical in form, and were connected to the surface by a vertical shaft of small diameter.

Tests were carried out to determine the shape of the earth mass involved when failure was induced by vertical loads acting along the axis of the anchor shaft. It was concluded that two distinct modes of failure existed. "Shallow" failure involved movement of a body of soil above the anchor along well-defined shear surfaces and was accompanied by radial and circular cracking of the soil surface. "Deep" failure took place within the soil mass and involved "tunnelling" of the anchor through the soil with no accompanying surface effects. The mode of failure depends on the ratio of depth of burial to anchor ball diameter. The critical value of this ratio for the two test soils used was found to be 10.

Further tests were used to investigate the load/displacement characteristics of a series of anchors of various sizes and burial depths, when subjected to vertical pull-out loads using a constant rate of strain technique. By comparing the measured ultimate pull-out loads with those predicted from existing theories (which were reviewed) it was concluded that none of these is entirely satisfactory. A theory developed in this dissertation was found to give more general agreement with test results in the "shallow" range of burial, although it was largely conservative in the "deep" range.

By examination of the load/displacement curves - particularly in their initial linear phase - it was possible to make design recommendations which would maintain anchor movement at working loads within specified or otherwise acceptable limits.

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31. Langley, Wilbert Spencer.
1967. Uplift resistance of groups of bulbous piles in clay. MS thesis, Nova Scotia Technical College, Halifax, Nova Scotia, 1967.

ABSTRACT

Experiments on groups of model piles with expanded bases have been made to determine the influence of number, length and spacing of piles, on the uplift capacity of groups of piles in clay.

Previous investigations on single piles with expanded bases have shown that the bearing capacity theory as developed by Meyerhof and Skempton can be applied to pile uplift resistance. The present work shows this to be true only if the depth of soil is great enough to develop the full pullout resistance. For depth of soil to base diameter ratios less than three the full theoretical pullout resistance cannot be developed.

It was found that for the pile groups tested there was a value of pile spacing for a given base diameter and soil depth at which the mode of failure changed. For closer spacings, failure was by the piles and soil enclosed within the perimeter of the group pulling out as a block. For wider spacings the block failure pattern was less pronounced and the pile group failed as individual piles.

The tests showed that the efficiency of a pile group, for a constant ratio of pile spacing to base diameter, increased with an increase in depth of soil to base diameter ratio. The efficiency for a group of piles at a given spacing and depth increases as the number of piles is increased. A spacing greater than five base diameters was found to be sufficient to develop the full pullout resistance of the group compared to the pullout resistance of the individual piles. For tests conducted on groups of pile shafts only, groups of four piles gave higher efficiencies than groups of two piles.

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32. Lee, H. J.
1972. Unaided breakout of partially embedded objects from cohesive seafloor soils. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R-755, Feb. 1972. NTIS/AD 740751.

ABSTRACT

The Naval Civil Engineering Laboratory has conducted field and laboratory tests to investigate the effort required to remove partially embedded objects from cohesive seafloor soils. This work is intended to aid in proper selection of elements for Navy salvage and rescue operations. This report presents the results of the tests and an analysis of the results. Procedures are given for use by field engineers in predicting forces required to remove objects immediately and in estimating times required when lesser forces are applied. The accuracy of the force prediction procedure is about plus or minus 50%; the accuracy of the time prediction procedure is about plus or minus 100%. These accuracies are comparable to those usually attainable with other time-dependent soil mechanics problems and should be acceptable for typical object retrieval operations.

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33. Liu, Cheng L.
1969. Ocean sediment holding strength against breakout of embedded objects. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R-635, August 1969. NTIS/AD 692411.

ABSTRACT

This report concludes 3 years of breakout force research. The third phase of the field test conducted in the Gulf of Mexico and a small-scale model study are described. All of the experimental results are presented in a new dimensionless correlation (between breakout force and breakout time) based on the mechanism of the breakout. The mean soil holding strength (F_m) is considered to depend upon average soil cohesion, object geometry, the time the object has been embedded (T_{in}), and the time allowed for pullout (T):

$$\frac{F_m}{F_r} = 1.5\left(\frac{T}{T_{in}}\right)^{-0.07} \qquad \text{for } 10^{-3} < T/T_{in} < 10$$

where F_r is the static soil resistance due to shear and tension. An example is also presented to illustrate the application of this equation. The small-scale model test is considered a useful tool in obtaining more data in future research.

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34. MacDonald, Harry F.
1963. Uplift resistance of caisson piles in sand. MS thesis, Nova Scotia Technical College, Halifax, Nova Scotia, 1963.

ABSTRACT

The object of this work was first to review the previous work published on the uplift resistance of caisson piles, and second, by means of laboratory tests to develop a more accurate relationship between uplift resistance and pile dimensions.

A review of previous work showed that the most commonly used design methods were the cone relationship and the cylinder relationship, neither of which proved accurate for all conditions.

A series of laboratory tests, including semi-spatial tests, were carried out in order to determine the variation of ultimate load with pile dimensions and soil variables. The semi-spatial tests showed that the failure surface was a parabolic cone in section, and not circular as previously

assumed. It was also seen that the failure shape was quite different when the depth to base diameter ratio of the pile was greater than five.

A relationship for the uplift resistance was setup by using a straight line approximation for the parabolic cone of the shallower tests. This was modified for the deeper tests first by using a cylinder instead of a cone, and second, by assuming that the failure surface was a cone at depth with a surcharge load. The uplift resistance was taken to be equal to the weight of the failure shape plus the shearing resistance along its boundaries. The lateral earth pressure coefficient was left as an unknown.

This relationship was checked against laboratory tests in order to obtain the correct lateral earth pressure coefficient. The final relationship was then tested against the results of full scale loading tests and was found to be quite accurate. The relationship was then modified to suit the characteristics of a displacement pile. Theoretical calculations showed a displacement pile to be considerably stronger in uplift than a corresponding cast-in-place pile.

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35. Matlock, Hudson, and Lymon C. Reese.
1962. Generalized solutions for laterally loaded piles. ASCE Transactions, Vol. 127, Part I, Paper No. 3370, pp. 1220-1251, 1962.

ABSTRACT

To reach rational solutions for problems of laterally loaded piles, the nonlinear force-deformation characteristics of the soil must be considered. This may be done by repeated application of elastic theory. Soil modulus constants are adjusted for each successive trial until satisfactory compatibility is obtained in the structure-pile-soil system. The computations are facilitated by non-dimensional solutions.

Basic equations and methods of computation are given for both elastic-pile theory and rigid-pile theory. Several forms of soil modulus variation with depth are considered. Typical solutions are presented and recommendations given for their use in design problems.

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36. Mayo, Henry C.
1973. Explosive anchors for ship mooring. Marine Technology Society Journal, Vol. 7, No. 6, Sept. 1973, pp. 27-34.

ABSTRACT

A 50,000-pound nominal capacity (XM-50) explosive embedment anchor and a 200,000-pound nominal capacity (XM-200) explosive embedment anchor have been designed and tested by the Army for application in ship mooring. Tests include determinations of anchor penetration, ultimate holding capacity, and short-term creep in most sub-bottom sediments except rock. Full-scale

mooring tests of a T-5 tanker and a Navy LST ship have been successfully accomplished. Test results have been incorporated in optimizing the anchor's physical configuration and installing procedure.

It is concluded that the two sizes of explosive anchors offer installing and operational advantages for ship mooring compared to conventional fluked anchors. Testing to date indicates that the explosive anchors will perform satisfactorily for ship mooring provided that they are properly installed.

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37. McKenzie, R. J.
1971. Uplift testing of prototype transmission tower footings. Proceedings of First Australian-New Zealand Conference on Geomechanics, Melbourne, Australia, Aug. 1971, Vol. 1, pp. 283-290.

ABSTRACT

This paper describes a series of uplift tests carried out by the State Electricity Commission of Victoria, Australia, on full size trasmission tower footings. Tests were conducted on bored piles in basaltic clay and buried slab footings in basaltic clay and in a granitic soil. Comparison of the pile test results is made with a "tension limited shear" theory developed from the results of an earlier series of uplift tests on piles of smaller capacity. (Ref. 1 and 2.) The effect of compaction and compressibility of backfill above concrete slab footings subjected to uplift loading is duscussed and the results are compared with a modified empirical cone theory.

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38. Meyerhof, G. G.
1973. The uplift capacity of foundations under oblique loads. Canadian Geotechnical Journal, Vol. 10, 1973, pp. 64-70.

ABSTRACT

The previous theory of vertical uplift capacity of foundations has been extended to foundations under oblique loads. The analysis is compared with the results of model and some field tests on rigid anchors and piles in sand and clay. The influence of load inclination on the uplift resistance can be represented by an interaction relationship between the vertical and horizontal components of the ultimate load.

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39. Meyerhof, G. G., and J. I. Adams.
1968. The ultimate uplift capacity of foundations. Canadian Geotechnical Journal, Vol. V, No. 4, Nov. 1968, pp. 225-244.

ABSTRACT

The ultimate uplift capacity of foundations with special reference to transmission tower footings is evaluated. A number of model uplift tests made by the authors and by others were studied and compared with full-scale tests. These tests showed a complex failure mechanism which varied with the depth of the foundation. Using simplifying assumptions a general theory was produced. It was shown that with suitable modification for shape and depth a useful relationship was available for computing the full-scale uplift capacity of foundations. It was further shown by model tests that the theory could be modified to take into account group action. Further research is required to evaluate the effect of combined loads and long-term effects.

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40. Migliore, H. J., and H. J. Lee.
1971. Seafloor penetration tests: presentation and analysis of results. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Aug. 1971, Technical Note N-1178. NTIS/AD 732367.

ABSTRACT

A series of eleven in situ penetration tests was conducted by the Naval Civil Engineering Laboratory (NCEL) at two seafloor sites. The objectives of these tests were to illustrate the capabilities of existing penetration evaluation equipment and to acquire data for use in evaluating a series of proposed penetration prediction techniques. The tests consisted of allowing two types of objects to free-fall into the seafloor with the accelerations experienced by the objects during penetration being recorded mechanically. The resulting data were subjected to a regression analysis which yielded information about the penetration mechanism but no practical results. This was followed by a physical analysis based on static soil mechanics relations. The latter analysis was shown to yield predictions of penetration depth which were within 50 percent of the measured values. A suggested prediction technique based on this analysis is presented.

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41. Muga, Bruce J.
1967. Bottom breakout forces. Proceedings Civil Engineering in the Oceans, ASCE Conference, San Francisco, Calif., Sept. 6-8, 1967, pp. 569-600.

ABSTRACT

Experimental studies were conducted in order to arrive at some appropriate engineering estimates of the force required to extract bodies of varying size and shape from various embedment conditions in the ocean bottom sediments. A review of the literature wherein breakout was an important consideration is presented.

From tests conducted in San Francisco Bay on various shaped objects having a submerged weight of up to 20,000 pounds, it was found that the following empirical formula described well the breakout force requirement

$$F = A_{max_6} \; q_d \; \cdot \; 0.20_e{}^{-0.00540 \; (t-260)}$$

where A_{max} is the horizontal propagation of the surface contact area
q_d is the bearing load supported by the marine sedimentary deposit
t is the time in minutes required to free the object.

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42. Muga, Bruce J.
1966. Breakout forces. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-863, Sept. 1966. NTIS/AD 836130.

ABSTRACT

Description of test procedures and preliminary analysis of the first of a three year effort on a study of breakout forces is presented. It is found that breakout is not a serious problem for the great majority of marine salvage operations, since the vessels are often rotated or pivoted before lifting. It is concluded that a theoretical procedure can be developed which will be useful in planning operational procedures.

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43. Muga, Bruce J.
1968. Ocean bottom breakout forces. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R-591, June 1968. Includes field test data and the development of an analytical method.

ABSTRACT

Theoretical and experimental studies were conducted in order to arrive at some appropriate engineering estimates of the force required to extract bodies of various sizes and shapes from the ocean bottom sediments. A review of the literature concerned with breakout forces is presented.

From tests conducted in San Francisco Bay on variously shaped objects having submerged weights of up to 22,200 pounds, it was found that the following empirical formula described well the breakout force requirement:

$$F = 0.20 \; A_{max} q_d \, e^{-0.00540 \; (t-260)}$$

where F = breakout force, lb
A_{max} = horizontal projection of the maximum contact area, in^2
q_d = average supporting pressure provided by the soil to maintain the embedded object in static equilibrium, lb/in^2

t = time allowed for breakout, min

Results yielded by the empirical formula agreed very well with a complicated theoretical procedure based on an iterative solution of a lumped parameter model of the ocean bottom. Solutions were obtained for various load conditions and bottom (object) geometries.

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44. Navy, Department of the.
1968. Design manual: harbor and coastal facilities. Naval Facilities Engineering Command, Washington, D. C., July 1968.

ABSTRACT

Design criteria are presented for facilities in category group 160 for use by experienced architects and engineers. The contents include harbors; coastal protection; dredging; ship channels; fixed moorings; fleet moorings; mooring design (physical and empirical data).

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45. Paul, Walter.
1969. A contribution to the anchoring problems of ships in the open sea. Paper given at the OECON '69 Offshore Exploration Conference in San Diego, Calif., March 7, 1969.

ABSTRACT

A contribution to the anchoring problem of floating rigs in the open sea is given.

1. The motions of floating rigs while anchoring in unsheltered waters are discussed.

2. A new taut anchoring system, using heavy synthetic fiber ropes and a special anchor piling set by hydrostatic pressure, is introduced.

3. A calculation method for this system is presented. It computes the stresses on the components while exposed to reactions of the rig to wind, current and waves. Results show that the properly designed system allows for the unavoidable heave and surge motions within the working elasticity of the ropes, though they may be prestressed at the same time by current and wind forces.

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46. Radhakrishna, H. S., and J. I. Adams.
1973. Long-term uplift capacity of augered footings in fissured clay. Canadian Geotechnical Journal, Vol. 10, No. 4, 1973, pp. 647-652.

ABSTRACT

The uplift capacity of augered footings in fissured clay is found to decrease substantially under the long-term sustained loads due to the loss of suction and softening of clay along fissures. Full-scale uplift tests show that the reduction in uplift capacity under long-term loads may be as much as 50% for cylindrical footings and anywhere from 30 to 50% for belled footings depending on the depth of footing.

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47. Raecke, D. A., and H. J. Migliore.
1971. Seafloor pile foundations: state-of-the-art, and deep-ocean emplacement concepts. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1182, Oct. 1971. NTIS/AD 889087.

ABSTRACT

A review of the state-of-the-art of the emplacement and design of seafloor pile foundations/anchorages was conducted. Several concepts for emplacement mechanisms suitable for use in water depths to 6,000 feet were considered, and a preliminary effectiveness evaluation of the mechanisms was conducted to reduce the number of systems for further investigation.

The state-of-the-art review indicates that marine drilling techniques and equipment could be readily adapted for deep-ocean pile emplacement for a very near-term requirement; however, the use of such a method would be quite costly. Other pile emplacement systems are presently limited to depths of about 1,000 feet by the need for relatively large amounts of power.

Development of a 6,000-foot pile foundation/anchorage emplacement capability is not limited by any need to develop novel mechanical equipment. Existing equipment can be adapted, or new equipment can be designed on the basis of proven principles. The most promising emplacement mechanisms for Navy development are: vibrators based on eccentric-weight or linear-oscillator devices, jack-in-mechanisms and screw-in systems. Selection of a single concept for further development can be accomplished in the near future. A moderate effort is required to more completely define the operating characteristics of the various types of emplacement mechanisms.

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48. Rossfelder, A. M., and M. C. Cheung.
1973. Implosive anchor feasibility study, final report. ECO Systems Management Associates, Inc., prepared for Naval Facilities Engineering Command, Chesapeake Division, under contract, Nov. 1973.

ABSTRACT

The propulsion of embedment anchors by means of hydrostatic pressure relief in a low-pressure chamber is analytically investigated. The feasibility and interest of such implosive anchors is demonstrated for deepwater applications and various conceptual configurations and design components are discussed. Critical areas of development are indicated and an engineering program is proposed. The novelty of the technology involved is inducive to several other developments in the area of deepwater implosive hardware.

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49. Schuette, H. W., and P. E. Sweeney.
1969. Mud and rock anchor feasibility and design study for multi-leg mooring system; phase 1, final report. U. S. Army Mobility Equipment Research & Development Center, Fort Belvoir, Va., Report No. ER-5885, Sept. 1969. NTIS/AD 860147.

ABSTRACT

This Phase I report covers feasibility investigations, design studies, evaluations and the selection of optimum mud and rock anchors for both the tactical and logistical facilities involved in the Tanker Multi-Leg Mooring System.

The primary purpose of this study program was to investigate means to extend the Tanker Multi-Leg Mooring System to include mud and consolidated rock. The mud and rock anchors shall be capable of developing holding powers of 50,000 pounds and 200,000 pounds in both mud and consolidated rock. The rock anchor shall have the capability of being driven through 25 feet of sediment overlaying a consolidated rock sub-bottom. This is accomplished by the addition of external power equipment attached to the basic rock anchor, which drives it through the sediment to contact the rock sub-bottom prior to firing the basic projectile.

The methods used in the performance of this program involved investigation of the state-of-the-art of mooring anchors. A literature survey was conducted to gather current data on both existing and developmental anchors. These data were classified, correlated and evaluated under a set of weighted parameters. The optimum mud and rock anchors selected and recommended for further development were based on the results of this study and evaluation.

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50. Sherwood, W. G.
1967. Developing a free-fall, deep-sea mooring system. Transactions of the Second International Buoy Technology Symposium, Washington, D. C., Sept. 18-20, 1967, pp. 19-35.

ABSTRACT

The requirement for mooring buoys and vessels in deep water with precision has long existed. AC-DRL has solved its deep water mooring problems through the development of a free-fail anchor system. These relatively lightweight anchor systems are used as mooring legs to multipoint moor a 310-ton research vessel with precision. When in the moor, with pre-tensioned surface mooring lines, the vessel's excursion in 5200 feet of water was held to 30 yards in winds up to 30 knots. Two types of free-payout, free-fall anchor systems were developed. These systems are described in detail along with the packaging techniques used. Both designs embody a single package containing the mooring wire and anchor. The surface end of the mooring wire is secured to its surface mooring buoy and, in succession, the buoy and anchor are dropped from the steran of the vessel. A pre-twist is placed in the wire as it is packaged, so that the wire is pulled out in a neutral state. A special bonding compound is used to encapsulate and restrain the wire in the package. The free-fall anchor system provides for a safe, rapid, economical method of deploying deep sea anchors in almost any sea state. System reliability has been demonstrated at sea in a comprehensive series of operational drops. During 1966 the R/V SWAN was moored on six separate occasions for periods of about ten days each, in water depths exceeding 17,000 feet. Future applications of such systems are discussed.

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51. Smith, J. E.
1954. Stake pile development for moorings in sand bottoms. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-205, Nov. 23, 1954. NTIS/AD 81261.

ABSTRACT

The U.S. Naval Civil Engineering Research and Evaluation Laboratory conducted tests on stake piles at Port Hueneme, California. The ultimate objective was to develop a family of stake piles of different holding powers corresponding to the mooring classes "AA" (300,000 lb) through "G" (5000 lb), which could be used in lieu of anchors in certain type moorings where the dragging of anchors is dangerous or objectionable. The project is divided into two phases, sand and mud bottoms, of which this report covers the first (sand bottom) phase in this development.

Initial tests were made on stake piles of several different designs to study the practicability of their use in class "CC" moorings (200,000 lb) or less and to establish criteria for the proper design of stake piles for class "AA" moorings. None of the original designs were entirely satisfactory for the class "CC" mooring, but data from the tests resulted in the development of a new stake-pile design incorporating fins and capable of meeting the class "AA" mooring requirement. Further tests on stake piles of the new design, in a firm sand bottom, indicated that under certain conditions such piles may be used successfully in moorings. Also, results demonstrated that three sizes of this stake pile design would fulfill the requirements of all mooring classes, (see Figure 25).

It was recommended that sand bottom testing be continued to provide data for further refinements on the design with reference to length of stake

pile and length and number of fins. It was further recommended that tests in a mud bottom should follow the completion of the sand bottom tests.

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52. Smith, J. E.
1963. Umbrella pile-anchors. Naval Civil Engineering Laboratory, Port Hueneme, Calif., May 20, 1963. NTIS/AD 408404.

ABSTRACT

Two umbrella pile-anchor designs were developed for use in moorings and dolphins. One design weighs about 1400 pounds and requires a casing for placement; the other weighs about 2200 pounds and is driven directly into the ground in a locked position, then opened. Tests indicated that both designs are operational in homogeneous soils free of boulders and other large obstructions. Both have bearing capacities and resistance-to-uplift capacities in excess of 300 kips in sand bottoms. Each design offers advantages for use in specific situations depending on such factors as fabrication costs, soil characteristics and depth of water at the driving site, and equipment available for placement.

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53. Smith, J. E.
1965. Structures in deep ocean, engineering manual for underwater construction, chapter 7: buoys and anchorage systems. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report 284-7, Oct. 1965. NTIS/AD 473928.

ABSTRACT

Technological developments affecting naval warfare requirements and the demands of scientific programs have directed emphasis on structures in deep ocean areas. The overall objective of this manual is to provide information on environments, systems, and techniques relative to construction in such areas. This chapter contains data on deep-water anchorage systems, for the restraint of structures on the surface, on the bottom, and at intermediate levels.

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54. Smith, J. E.
1966. Investigation of embedment anchors for deep-ocean use. Paper presented at the Petroleum Mechanical Engineering Conference, New Orleans, La., Sept. 18-21, 1966, of the ASME.

ABSTRACT

Two commercial types of explosive-embedment anchors, here designated "Blue" and "Brown," were tested to examine their potential for application in deep-ocean anchorage systems. Tests were conducted both in sand and mud bottom conditions in shallow water and in depths to 6000 ft. Components of the anchors were subjected to pressures as great as 10,000 psi in the Deep Ocean Simulation Laboratory. Successful discharges and embedments were achieved with Blue anchor in depths to 6000 ft and Brown anchor in depths to 1200 ft. In general, a large percent of the tests resulted in malfunctions or in below nominal rated holding capacities. However, causes of malfunctions were traced to correctable causes in most cases, and the low holding powers were believed due in part to control of anchor altitude when discharged into the bottom and to operational problems. It is concluded that the principle of explosive-embedment anchors offers reasonable potential for development of deep-ocean anchors that will be better than any now known to exist. Also, both commercial types of explosive anchors possess approximately equal potential but with different deficiencies to overcome.

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55. Smith, J. E.
1966. Investigation of free-fall embedment anchor for deep ocean application. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note 805, March 1966. NTIS/AD 808818.

ABSTRACT

The concept of a free-fall type of anchor that could be rapidly and surely placed and used to secure small to moderate size objects such as buoys, floats, and barges on station in great depths of water was investigated. Two experimental anchors were designed and tested. Major problems were encountered in (1) achieving adequate velocity through the water which resulted in a lack of adequate penetration into the bottom; (2) in accommodating the anchor line; and (3) in maintaining weight, size and proportions within practicable bounds. Consequently, the free-fall anchor concept as it applies to specified objectives and criteria was found to be not feasible. However, the anchor fluke designed for one of the experimental anchors and the method used for anchor line payout during its free-fall placement are considered worthy of further investigation in conjunction with other contemplated operations.

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56. Smith, J. E.
1971. Explosive anchor for salvage operations - progress. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1186, Oct. 1971. NTIS/AD 735104.

ABSTRACT

An explosive anchor for salvage operations was designed, fabricated, and tested. The primary objective was to alleviate the critical problem of anchoring in coral seafloors but it also was desired to incorporate as broad a range of salvage anchoring capabilities into the new anchor as

possible. The prototype is 12 feet high, has a 10-foot circular base and weighs about 6 tons. It functioned in coral and developed a holding capacity greater than 150,000 pounds. It also demonstrated potential for service in other seafloors and over a wider range of operational conditions. Further development is proceeding to reduce anchor size and weight and to simplify and make the ordnance system more reliable so that it will meet acceptable operational standards.

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57. Smith, J. E., and P. A. Dantz.
1963. A perspective on anchorages for deep ocean constructions. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note TN-552, Dec. 1963. NTIS/AD 426202.

ABSTRACT

A preliminary survey of anchorages for deep ocean construction was made to define areas where present technology is lagging. This report summarizes the findings by discussing requirements, present technology, and major problems. A proposed program to develop a deep ocean anchorage capability is offered.

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58. Smith, J. E., and J. V. Stalcup.
1966. Deadman anchorages in various soil mediums. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Apr. 1966, Technical Report R-434. NTIS/AD 631848.

ABSTRACT

A test program was conducted to investigate deadman anchorage holding capacities under applied horizontal loads. Deadmen fabricated of concrete and ranging in face area from 5 to 72 square feet were tested in depths of embedment from ground level to 7 feet. The deadmen were pulled both singly and in groups of three, in sand and in two soils with cohesive characteristics. The test program also included tests on a model scale.

The applied load versus horizontal displacement relationship exhibited a basic recognizable form for all conditions of tests. By graphic analysis, a series of reaction-pattern curves was developed relating deadman holding power in each cohesive soil to three factors: deadman face area, depth of embedment, and whether the deadmen were embedded singly or in a group. The results of the sand tests which were described in a previous report were converted from the previous analysis to a compatible form and presented with the cohesive soil test results. These curves provide an empirical means for determining deadman holding capacities at different amounts of displacement within the range of conditions tested.

The investigation disclosed that multiple anchors develop a higher holding capacity per net area than a single deadman with the same total face area. The increase in holding capacity ranging from 5 to 20% depends upon such

factors as depth of embedment, the type of soil, and the spacing between deadmen. Under most test conditions, up to a 30% increase in holding capacities was attained in cohesive soils as compared to sand, but 2 to 3 times the horizontal displacement was required to achieve the maximum holding capacity.

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59. Smith, J. E., R. M. Beard, and R. J. Taylor.
1970. Specialized anchors for the deep sea - progress summary. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1133, Nov. 1970. NTIS/AD 716408.

<u>ABSTRACT</u>

Five anchor design concepts have been explored in conjunction with the program to develop an improved deep sea mooring capability. The knowledge gained from study of these anchor concept, (1) "Free-fall", (2) "Pulse-jet", (3) "Explosive", (4) "Padlock", and (5) "Vibratory", are summarized in this report.

The vibratory anchor is currently the center of the deep sea anchoring development effort. A first generation design has demonstrate the concept to be feasible. Tests have shown that improvements are required for the vibratory anchor. An analytical study has been performed to assist in optimizing a second generation design. Improvements incorporated in the second generation design will be based on information from tests of the first design and the analytical study. The improved design will be tested in a range of seafloor sediment types and water depths to rate its capabilities and establish its reliability.

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60. Sowa, V. A.
1970. Pulling capacity of concrete cast *in situ* bored piles. Canadian Geotechnical Journal, Vol. 7, 1970, pp. 482-493.

<u>ABSTRACT</u>

The pulling capacity of cylindrical concrete piles cast *in situ* in bored holes is examined for piles constructed in sandy or cohesive soils. On the basis of the data presented, it is concluded that the pulling capacity of these piles in cohesive soils can be estimated approximately, while the pulling capacity of piles in sandy soil is considerably more difficult to estimate. Estimating the pulling capacity of piles in cohesive soils is based on an empirical relationship between soil adhesion and the undrained shear strength. A possible explanation for the difficulty in estimating the pulling capacity of piles in sandy soils is suggested.

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61. Spence, Walter M.
1965. Uplift resistance of piles with enlarged base in clay. MS thesis, Nova Scotia Technical College, Halifax, Nova Scotia.

ABSTRACT

The object of this work was to review the previous work published on the uplift resistance of bulbous piles with particular reference to their behaviour in clay, and then by means of laboratory tests to check out previous theories and, if necessary, to develop new relationships between the uplift resistance and the soil and pile characteristics.

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62. Sutherland, H. B.
1965. Model studies for shaft raising through cohesionless soils. In Proceedings of the Sixth International Conference on Soil Mechanics and Foundation Engineering, Montreal, Canada, Sept. 8-15, 1965., Vol. 2, pp. 410-413.

ABSTRACT

At Sizewell Nuclear Power Station, eight vertical shafts were constructed from the cooling water tunnels by jacking cylindrical linings vertically from the tunnel to sea bed level. This shaft raising was carried out in cohesionless soil through a depth of about 20 ft. The problem of determining the required jacking loads is similar to that of the tensile loads required to pull out pylon foundations. As no satisfactory theory exists for the calculation of these loads, the problem was resolved by the use of model experiments. The jacking loads required in the field fell within the range of those predicted from the model studies.

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63. Taylor, R. J., and R. M. Beard.
1973. Propellant-actuated deep water anchor; interim report. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Aug. 1973. NTIS/AD-765 570.

ABSTRACT

A propellant-actuated deep water anchor is being developed to moor deep ocean surface and sub-surface structures. The anchor is designed to have a long-term holding capacity of 20,000 pounds and function in seafloors ranging from very soft sediments to hard rock (basalt) in water depths to 20,000 feet. The anchor has been designed, fabricated, and tested on land. Deep water use of this anchor requires that it be expendable; therefore, surplus ammunition components are used in the launching system (e.g., gun barrel, cartridge, primer), and a simplified structural shape is used for the reaction vessel.

Three anchor flukes (one for rock and coral, one for sand and stiff clay, and one for soft clay) were designed to satisfy the realm of seafloor anchoring possibilities. Results of the land tests were that actual and predicted launching system performance were comparable within 9%, and the anchor launch vehicle was structurally sound. The anchor will be tested in a range of water depths and seafloor types to complete the development phase.

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64. Taylor, R. J., and H. J. Lee.
1972. Direct embedment anchor holding capacity. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1245, Dec. 1972. NTIS/AD 754745.

ABSTRACT

Techniques for predicting the maximum uplift forces which may be applied to direct embedment anchors without causing the anchor to pull out are provided. This holding capacity problem is subdivided into three categories: immediate breakout, long-term static load, and long-term repeated load. Holding capacities under long-term repeated and long-term static loading conditions are poorly understood at present. It was therefore necessary to combine work from other areas with a small amount of directly applicable work to yield approximate immediate use results. For each manner of loading considered, two general types of seafloors are considered: cohesionless and cohesive soil. Rock is not considered in this report.

To simplify the holding capacity prediction process, the suggested procedure is outlined without rationale in a block diagram with each item of the diagram being briefly discussed. A sample problem is also presented.

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65. Timar, John G., and Stanley M. Bemben.
1973. The influence of geometry and size on the static vertical pullout capacity of marine anchors embedded in very loose, saturated sand. University of Massachusetts, School of Engineering, Amherst, Mass., prepared for Dept. of Defense, March 1973, Report No. UM-73-3, NTIS/AD-761623.

ABSTRACT

The design of several types of anchorages and mooring systems for marine installations is predicated upon the accurate calculation of the vertical pullout capacity of those anchorage systems. Involved in the solution of the vertical pullout capacity of embedment anchorages are the engineering properties of the confining soil; the duration of the loading period; and depth, size and shape of the anchor flukes.

The purpose of this testing program was to investigate the behavior of anchor flukes of several different geometries and sizes in a very loose, saturated sand. It was desired to determine which, if any, of the flukes provided the maximum vertical pullout capacity under static loading conditions, and whether any size effects upon pullout capacity existed.

Flat and skewed flukes of square, circular and rectangular shape and 55, 110 and 220 square inches in projected area were tested in an outdoor test facility of concrete. Full-section and semi-spacial models were tested in the laboratory for visual observation of the mode of failure.

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66. Tolson, Billy E.
1970. A study of the vertical withdrawal resistance of projectile anchors. MS thesis, Texas A&M University, College Station, Tex., May 1970.

ABSTRACT

There is a great need for anchors with high resistance to withdrawal that can be placed quickly and economically. Also high resistance anchors are required in areas where excavation for conventional anchors can not be accomplished. Seeking a solution to these anchoring problems, this research was undertaken to determine the magnitude of the holding power which can be developed by firing projectiles into the earth.

Projectiles were fired into soil targets and then withdrawn. The withdrawal resistance was determined for several projectiles.

Results indicate that tremendous resistance to withdrawal was developed for relatively small depths of imbedment. An empirical equation using statistical methods was generated to predict the withdrawal resistance.

It is considered that this research is only the beginning work for investigating withdrawal of projectile anchors.

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67. Trofimenkov, J. G., and L. G. Mariupolskii.
1965. Screw piles used for mast and tower foundations. In Proceedings of the Sixth International Conference on Soil Mechanics and Foundation Engineering, Montreal, Canada, Sept. 8-15, 1965, Vol. 2, pp. 328-332.

ABSTRACT

In this report the results of screw pile tests are described and the method of determining their bearing capacity is given. About two hundred piles were tested, the pile plate diameter being 0.25 to 1.0 m. Loads which were continuously increasing, pulsating, alternate, and increasing

by steps were applied on these piles. Pressing in and pulling out tests were conducted. Both single piles and groups of piles were tested. On the basis of the tests, the method of determining the allowable load of the screw piles was developed, based on the bearing capacity of the soil and on the allowable deformation of a pile.

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1975. Penetration of projectiles into seafloor soils. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report R-822. NTIS/AD-A011808.

ABSTRACT

This report presents Laboratory model tests and field tests of a study conducted on projectile penetration into seafloor soils. Existing relationships for predicting penetration behavior are considered, and new relationships are developed to account for observed test results. The derived relationships incorporate conventional soil engineering properties with special modifications to account for the effects of velocity, penetrator shape, and penetration depth on penetration resistance. These relationships are shown to compare favorably with previously available methods for predicting penetration depths where soil properties are known. Recommendations are presented for the evaluation of constants in the relationships. A calculation procedure is presented for solving the penetrator equations of motion by hand or with the aid of a small computer. An example problem is solved by hand to illustrate the use of the proposed relationships in the calculation procedure. Recommendations are made for use of results in preliminary and detailed engineering work.

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1975. Expedient deep-water propellant anchor mooring system. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Note N-1413, Nov. 1975. NTIS/AD-A021842.

ABSTRACT

The Civil Engineering Laboratory has investigated the best means for installing CEL 20K Propellant Anchor quickly, effectively, and efficiently in the seafloor. This anchor can achieve holding capacities of 20,000 pounds in water depths of 20,000 feet. Several concepts were examined for launching the anchor system and deploying the anchor and line. Also included were advanced concepts for laterally distant anchor deployment. Alternate components were identified, and candidate systems were synthesized and evaluated.

A buoy-launchable, free-falling, bale-on-anchor system was selected as best satisfying the broadest range of foreseeable needs. Preliminary

design information is given for this "standard expedient mooring system package." The system includes a feature for automatic length adjustment, stopping, and locking of the line at the anchor to provide a taut surface moor; this feature can be deleted to reduce cost. The package can be towed to a site or launched from a suitable carrier. A launching system is described that permits the proposed package to be launched from most surface vessels having an open cargo deck capable of accommodating the size and weight of the package; no ship-borne load-handling equipment is required.

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1962. Uplift resistance of transmission tower footings. ASCE Proceedings, Journal of the Power Division, July 1962, pp. 17-33.

ABSTRACT

The results of a research project undertaken to develop design criteria for tower foundations subjected to uplift loads is presented herein. The study was directed primarily to the evaluation of uplift resistance of under ream type footings. Limited results for straight concrete shaft and grillage footings are also presented.

The study has defined empirical relationships between uplift resistance, footing dimensions, and soil properties for shallow and deep footings. Footings with a depth-diameter ratio in excess of 1.5 are considered as deep footings. Although the criteria developed are empirical, the equations permit a more reliable evaluation of uplift resistance than previous methods of design based on assumed dimensions of the soil failure surface. A comparison of several methods with the equations developed by the study is also presented.

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ABSTRACT

The performance of eight hydrostatic anchors was evaluated in a cast iron tank 30 inches wide, 72 inches long, and 32 inches deep to study the efficiency of underwater suction in the soil. The soils studied were a silt and a clay. A gantry-type loading mechanism was used to apply the vertical breakout force. A pullout rate of approximately 0.1 in/min was used for all tests.

The vertical breakout behavior of the hydrostatic anchor depends greatly upon the anchor geometry including anchor diameter and skirt length, the soil strength properties, and the pressure difference between the ambient

pressure and that underneath the porous stone. For the range of conditions studied, the anchor capacity increased linearly with increasing pressure difference provided that the anchor skirt length to diameter ratio remained constant. A theoretical analysis based upon the Coulomb failure theory resulted in an equation which predicts satisfactorily the experiment results.

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ABSTRACT

The object of the present research was to review the previous work on the uplift resistance of single caisson piles and then with the aid of laboratory tests, to develop a relationship for the uplift resistance of groups of caisson piles in sand.

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1971. The behaviour of groups of anchors in sand. PhD thesis, Sheffield University, Dept. of Civil & Structural Engineering, England, 1971.

ABSTRACT

The object of this research study was to investigate the subject of the behaviour of groups of anchors in sand. To achieve this several series of laboratory scale experiments on anchors in a dry sand were carried out. Special studies were made of the effects of repetitive loading, and loading of an individual anchor in the group. Photographic studies of the displacements of the sand in the vicinity of a group of anchors were made in a glass-sided flume.

The main findings of this study are that the behaviour of a group of plate-shaped anchors is dependent on the size and shape of the group, the arrangement and spacing of the anchors in the group and the relative depth of embedment of the anchors.

The present research work has shown that the anchor group problem is a very complex one and is one which, when solved, can have a significant influence on current design practice. Many parameters have been shown to be in need of further and detailed study. These are listed at the end of the thesis.

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1965. Comparison of results of various anchor tests by AEP. Paper recommended by the IEEE Transmission and Distribution Committee of the IEEE Power Group for presentation at the IEEE Summer Power Meeting, Detroit, Mich., June 27-July 2, 1965, American Electric Power Service Corp., New York, N. Y.

ABSTRACT

Transmission tower anchors of various types have been tested by AEP at several locations. These include many guy anchor designs plus concrete and steel grillage types for self-supporting towers. Several anchors of each type were installed at different depths and with variations in backfill, moisture content of soil, and anchor size. Test results are plotted to compare load-creep characteristics of the various anchor installations. More than 210 tests were performed on 20 types. Results clearly show the advantages of using certain of the types and installation procedures in specific soil conditions over other types and procedures. Following tests, some were discarded from further consideration because of poor performance or cost of installation. Considerable test data is included for others to evaluate and use as they see fit.

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